

Many computer-based systems are orders of magnitude more complex than the wireless information appliances that are the current focus of much of the attention of the computer science community. They are often safety-critical systems that have become an important part of the global economy and our daily lives, such as air traffic control, commercial and military aircraft, commercial shipping, municipal rapid transit networks, regional power plants, and oil and natural gas pipelines. This panel calls attention to the problems of interacting with complex, automated systems, describes applications in which appropriate technologies have been successfully applied in the human/machine interface, and points to challenging research issues.

David Zeltzer

David Zeltzer is vice president and chief technical officer at the Fraunhofer Center for Research in Computer Graphics (CRCG) in Providence, Rhode Island. He is also adjunct associate professor of computer science at Brown University. In addition to work in virtual environment technology, his research interests include human-machine interface design and knowledge-based visualization systems. He is a senior editor of the MIT Press journal *Presence: Teleoperators and Virtual Environments* and he is the author or co-author of more than 30 technical publications on virtual environments and human-machine interfaces.

Bill Buxton

The three basic rules of real estate (Location! Location! Location!) apply just as well to human-machine interface design. Tell me where a system or device will be used, and I will know an awful lot about its interaction and usability requirements. We can learn a lot from technologies developed by native peoples that allow them to negotiate hostile environments, which would render useless many of our much-touted wireless, GPS-equipped devices. The lesson is that less is more. Throwing technologies at a problem is far less important than understanding well the needs and capabilities of the human users. This applies across a wide range of computer-based systems being deployed today.

Bill Buxton is chief scientist at Alias|Wavefront and its parent company SGI, as well as an associate professor in the Department of Computer Science at the University of Toronto. He is a designer and researcher concerned with human aspects of technology, and his work reflects a particular interest in the use of technology to support creative activities such as design, filmmaking, and music. His research specialties include technologies, techniques and theories of input to computers, technology-mediated human-human collaboration, and ubiquitous computing.

Christopher A. Miller

Applying sophisticated, adaptive, and intelligent "information presentation automation" to manage information flow to human consumers in complex systems and domains is not a panacea. At SMarT Information Flow Technologies, our experience includes design of adaptive automation and information systems for

multiple "high-end" domains including fighter piloting, attack/scout helicopter piloting, petrochemical refining, and communications resource management for military command and control. Users in such domains are very demanding and critical of automation that does not behave according to their standards and expectations, and it has proven difficult to create systems that are correct enough to achieve user acceptance. Yet we have found that intelligent interfaces and behaviors can be designed so that perfection is not required, but that value is still provided. Such interfaces require detailed consideration and design of the human-automation relationship. A critical mistake is attempting to make the system too autonomous in its behaviors. Instead, the opportunity for explicit and dynamic collaboration about how the system may best serve the human is critical.

The rotorcraft pilot's associate cockpit information manager (RPA) adaptive information management system provides an example. RPA achieved acceptable levels of usability and statistically significant workload reduction compared to an unaided condition in a series of complex and realistic human-in-the-loop mission simulations. It is important to note that these results were obtained in spite of less-than-perfect tracking of the pilot's intent and pilots' reports of having to "now and then" override or correct RPA's behaviors.

One innovation we employed in the RPA cockpit may have influenced these results: a "Crew Coordination and Task Awareness" display that, unlike some previous systems, gave the two human crew members direct insight into, and some control over, RPA's notion of the mission context and main tasks of each crew member. Pilots' acceptance of this display was very high, averaging 4.25 on a scale of 1-5 where 4 corresponded to "Of Considerable Use" and 5 to "Extremely Useful."

The success of this interface innovation has led us to think more seriously about the implications of the associate metaphor for adaptive automation in many domains. Given our experience in working on intelligent information systems, and our familiarity with others in the literature, we have recently drafted a set of "etiquette rules" for adaptive-system behavior. The notion of etiquette rules seems to have an appropriate focusing effect, both placing an emphasis on behavior acceptable to a human supervisor and requiring a degree of anthropomorphic thinking about the system, which seems to be productive. In this panel, these rules are presented, and the general notion of human-machine etiquette is discussed, along with additional examples from RPA concerning the quantification and tradeoff among rules implemented in that program.

Christopher A. Miller is chief scientist of SMARt Information Flow Technologies (SIFTech). He has over 11 years' experience in creating knowledge representations and computational approaches to adaptive user interfaces, automation, and decision aids. Until recently a research fellow at Honeywell Laboratories, he has led intelligent, adaptive information-system design efforts for domains including management of military communication resources, fighter piloting, attack/scout helicopter piloting, oil refinery operations, commercial aviation operations, and ground-based dispatch operations.

References

Banks, S. and Lizza, C. (1991). Pilot's associate; A cooperative knowledge-based system application. *IEEE Expert*, June. 18-29.

Miller, C., Hannen, M., & Guerlain, S. (1999). The rotorcraft pilot's associate cockpit information manager: Acceptable behavior from a new crew member. In *Proceedings of the American Helicopter Society's FORUM 55*, Montréal, Québec, May 25-27.

Robert J. Molloy

The "pitfalls" of automation in the modern glass cockpit have been a topic of discussion for over 20 years. Concurrent with increased automation in the cockpit, however, has been the increased deployment of automation in surface modes of transportation: transit trains are being operated in fully automated environments, pipeline operations are becoming more centralized and computerized, and maritime operations have seen increases in automation on both the bridge and engine rooms with subsequent reductions in manpower. Visions of the future include single-manned ships operating across the oceans. Even highway transportation is moving to highly automated systems with the development of the intelligent transportation system.

Unfortunately, surface modes seem to be experiencing the same difficulties in the growth of automation that faced the aviation industry in the past. The National Transportation Safety Board's investigation of the grounding of the cruise ship *Royal Majesty* off the shores of Nantucket came across several deficiencies in automated systems on the bridge. Systems that could have prevented the grounding were turned off due to high false-alarm rates. Systems that controlled the movement of the ship were able to fail in ways unanticipated by the crew. Finally, crew complacency and trust in the system prevented adequate monitoring of the systems. The board's investigation of a pipeline rupture in 1996 near Gramercy indicated that the maritime industry was not alone in its discovery of the "pitfalls" of automated systems. The pipeline controller failed to recognize the significance of an alarm due to the high frequency of alarms in the system. Further, the alarm that signaled a leak was given no higher priority than any other alarm.

Central to these discussions is the danger of moving the operator from direct control to passive monitoring. As the operator becomes less involved in direct control, there is the possibility of losing awareness of the system's state or position in the environment. The National Transportation Safety Board investigated one such occurrence in Cali, Columbia with the crash of American Airlines flight 965.

Accidents such as the *Royal Majesty* grounding and the Gramercy spill indicate that the problem of poor automation implementation continues to occur in surface modes. As such, more must be done to ensure that we do not revisit each of the "pitfalls" of automation previously discovered in the aviation field.

Rob Molloy joined the National Transportation Safety Board in May 1996 as a transportation research analyst. While at the board, he completed a study of aircraft evacuations and statistical reports on occupant survivability in aircraft accidents, and the relationship between accidents and aircraft age. He is currently co-managing a safety study on supervisory control and data acquisition systems in the pipeline industry. He has also been involved in accident investigations involving automation issues in multiple modes of transportation.

Steve Chien

Traditionally, NASA has used robotic spacecraft to explore the far reaches of the solar system by carefully designing spacecraft for the expected environment and controlling the spacecraft using a highly skilled operations team. Next-generation missions involve exploration of rapidly changing environments in situ, such as a lander on the surface of a comet, a submersible in oceans below the ice caps of Europa, and an aerial explorer in the fluctuating atmosphere of Titan. These explorers will need an unprecedented level of autonomy and adaptability to survive, in order to achieve their science goals. Yet other missions propose large numbers of cooperating explorers, such as swarms of rovers, penetrators, and airplanes, to study the climate of Mars.

These semi-autonomous systems present unique interface and interaction issues for their designers and operators. Designers must be able to determine and envision system performance in a wide range of operating scenarios. Operators must be able to understand the effects of high-level goals now used to command the autonomous explorers. The interaction between humans and space systems becomes a peer-to-peer negotiation, and succinctly summarizing group behavior is critical when tracking large numbers of autonomous entities.

In my presentation, I describe some of the challenges of this mixed-initiative, peer-to-peer model, as well as preliminary work at JPL to address these problems.

Steve Chien is technical group supervisor of the Artificial Intelligence Group and principal computer scientist in the Exploration Systems Autonomy Section at the Jet Propulsion Laboratory, California Institute of Technology. At JPL, he leads efforts in automated planning and scheduling for space exploration. He is the technology community lead for autonomy for JPL. He is also an adjunct associate professor with the Department of Computer Science, University of Southern California.



A collection of autonomous rovers and space vehicles that may be part of the scientific exploration of Mars. Jet Propulsion Laboratory, California Institute of Technology